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THE TRUSTEES OF
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DESCRIPTION OF THE IGNEOUS ROCKS REPRESENTED AMONG PEBBLES FROM THE BUNTER PEBBLE BEDS OF THE MIDLANDS OF ENGLAND

By W. CAMPBELL SMITH

A LARGE and representative collection of pebbles from the Bunter Pebble Beds in the Midlands, particularly from the neighbourhood of Birmingham and from Cannock Chase was made by Professor L. J. Wills over a period of years. During much of this time he was Professor of Geology in the University of Birmingham and he enlisted the assistance of a team of other geologists which at various times included F. W. Shotton, A. Lamont, C. E. Marshall, and W. Jeavons.

The localities from which the sliced pebbles of igneous rocks were collected are as follows :—

Number		Ref. O.S. 1″ map	Grid. ref.[1]
BP. 4	Old Quarry, Wollaston Ridge, nr. Stourbridge	131 (1962)	3881/2840
BP.17	Ridge Street, Wollaston Ridge, nr. Stourbridge	131 (1962)	3883/2849
BP.31	nr. Trysull, 7 miles NW. of Stourbridge	130 (1954)	385–/294–
BP.45	Blackhills Quarry, Swindon, 5 miles NW. of Stourbridge	130 (1954)	3842/2921
BP.32	Star Gravel Pit, Great Barr	131 (1962)	4046/2951
BP.33	Queslett	131 (1962)	4061/2947
BP.35	Keeper's Pool, Sutton Park	131 (1962)	4107/2966
BP.38	Bristnall Fields, Warley (by small reservoir)	131 (1962)	3003/2870
BP.52	Old Quarry by schools, Warley	131 (1962)	3015/2865
BP.41	Oakamoor, E. of Cheadle	120 (1962)	4052/3448
BP.42	¾ mile E. of Polesworth, E. of Tamworth	120 (1962)	4274/3029
BP.43	Hopwas Sand Pit, W. of Tamworth	120 (1962)	4176/3051
BP.44	Weeford Works, Canwell, 1¼ miles S. of Weeford, W. of Tamworth	120 (1962)	4138/3019
BP.89	Upper Stonnal, 9 miles W. of Tamworth	120 (1962)	4062/3037
BP.20	Rubery	131 (1962)	3994/2774
BP.51	Sling Common, Clent	131 (1962)	3946/2740
BP.53	Farley Wood, Romsley	131 (1962)	3953/2784
BP.63	Fields nr. Walton Pool, Clent	131 (1962)	3939/2787
BP.68	Barns Close, and Chapmans Hill, Romsley : also Chadwick Grange	131 (1962)	3970/2772
BP.61	All drift pebbles (mostly Moseley)		

[1]In these references the first figure of each set of four refers to the 100 km. squares of the Grid, now usually indicated by letters, e.g. 4176/3051 = (43) 176/051 = SK 176051.

Professor Wills has given a brief, general statement of the make-up—local and exotic—of the pebble content of the basal shingle beds of the Bunter in his book on Concealed Coalfields (1956, pp. 112–3). Quartzite and vein-quartz pebbles are estimated together to average 80–90 per cent. by weight of the beds examined. The remaining 10–20 per cent. is made up of a varied assemblage of sedimentary, metamorphic and igneous types.

Wills has remarked that in considering the composition of the Pebble Beds as a whole due allowance must be made for the fact that in general only the tougher and less easily weathered rock-types had reached the Budleigh Salterton and the Midland areas. In the Midlands Wills has recorded large specimens (i.e. over about $6 \times 6 \times 5$ ins.) of all the quartzites and all the other tough varieties. He notes among these large boulders that rhyolites are rare unless tourmalinized or silicified. The wear in river transport and in flood-waters capable of carrying the large boulders has eliminated such relatively soft rocks as granite, schists, some sandstones, slates and shales. Limestones too have probably been dissolved since their deposition in the Pebble Beds though some have survived in deeply buried parts of the formation.

Some other moderately tough or hard rocks are observed to have undergone partial decomposition, probably effected by percolating waters, since their deposition in the Pebble Bed. Examples are certain igneous rocks too rotten to section, and some of the Carboniferous black cherts with crinoids preserved in calcite. The latter are altered to a white soft rock with cavities marking the sites of crinoid ossicles. Even some of the quartz-porphyries found *in situ* while retaining their outward form prove, on removal from the bed, to be quite friable inside.

Wills has assembled a large collection, now in the Geology Department of Birmingham University, representative of all the types of pebbles but naturally richer, numerically, in the unusual ones.

The pebbles that I have examined are those igneous ones of which thin sections have been made. In addition to these, there are not only large numbers of pebbles similar to the sliced specimens, but also a considerable number of pebbles of " soft igneous " rocks of which the condition is such that thin sections can only be made after thorough impregnation of the specimens.

In describing the pebbles and sections I have had in mind that the descriptions should be sufficient to enable anyone who reads them to recognize the main characters of the types. I have tried to lay stress on easily recognizable or conspicuous characters and to describe what is readily seen in the thin sections without being too particular about exact identifications. This is very much the case as regards the feldspar. The name " orthoclase " for instance is used in an old-fashioned way for feldspar with the right order of refractive index and without visible albite twinning. Similarly it will be found that little time has been spent by me on measuring up the plagioclases and accurately determining them. If in time to come close comparisons of igneous rocks at outcrop with pebbles from the Bunter can be made then detailed work on the feldspar and more careful identifications of some other minerals will be needed.

A list of the specimens examined and descriptions of the thin sections has been prepared and will be filed with the collection at Birmingham.

DESCRIPTIONS OF THE IGNEOUS ROCKS

The following is a summary of the results with descriptions of good examples of the various kinds of igneous rock encountered.

The pebbles of the igneous rocks examined have been classified under the general headings of : Granites (and granophyres) ; Quartz-porphyries ; and Rhyolites.

Granites

The collection of sectioned pebbles contains about two dozen pebbles of granitic rocks, all rather leucocratic. A few contain small amounts of biotite and some are tourmalinized. None of them offer much chance of identifying the outcrops from which they came.

Some of the more leucocratic granites contain muscovite as well-formed flakes : in others fine-grained muscovite (sericite?) occurs but appears to be secondary. Some of these are strongly foliated.

An example of the muscovite-bearing granite is :— 8.657.BP.51/32, from Sling Common, Clent.

The pebble shows grey quartz in lenticles or layers in a very pale pink-and-white or cream-coloured groundmass of altered feldspar. There are some flakes of muscovite visible in the pebble and many small black patches. The thin section shows that the black opaque patches apparently due to iron oxide (?), are filling little cavities ; perhaps this is a later introduction. The muscovite flakes are quite fresh. They lie among medium-grained quartz and feldspar with much cataclastic material. The rock is foliated. Perhaps it might derive from a muscovite-gneiss.

Tourmaline occurs in several of the leucocratic granites, sometimes unaccompanied by either muscovite or biotite (2.112.BP.51/37) but in some pebbles associated with flakes of muscovite (2.136.BP.51/10) or accompanied by secondary muscovite as in :— 8.670.BP.4/1., from Wollaston Ridge, Old Quarry. This is a compact, fine-grained, light russet vinaceous pebble, with grain-size averaging 0·5 mm. The tourmaline occurs as occasional groups of radiating prisms, pleochroic from colourless to blue, and the muscovite, as well-developed flakes, appears to be replacing feldspar, probably plagioclase. The orthoclase feldspar is turbid in thin section and tends to occur in plates enclosing rounded " blebby " quartz.

In the biotite-granites the biotite is usually replaced by opaque " iron oxide". Occasionally it is partly altered to green chlorite, and in two of the sections examined the biotite is still fresh and pleochroic. One of these is from Guest's pit, Wollaston Ridge (2.137.BP.17/1).

This pebble is speckled, pallid purple-drab[1], and medium to fine in grain-size. It shows pale-grey quartz crystals in dull white feldspar. There are frequent flakes of mica visible. Under the microscope it is seen that the texture is allotriomorphic

[1]Colours are described with reference to R. Ridgway, " Color standards and color nomenclature ". Washington, 1912.

granular. The feldspar is mainly orthoclase, but some, although showing no twinning, has refractive index greater than balsam and less than quartz. The biotite is fresh and pleochroic from straw yellow to dark (olive) brown. Apatite is a frequent accessory.

Granophyres

Four of the pebbles are classified as granophyre though in one case the granophyric fabric is extremely fine-grained (micro-granophyre). This pebble is probably from a dyke rock. It is deep livid brown to vinaceous brown in colour and it resembles superficially some varieties of the Elfdalen porphyry. It is 2.177.BP.42/1 from $\frac{3}{4}$ mile E. of Polesworth, nr. Tamworth.

Another very fine-grained granophyre shows on the surface of the pebble large black patches of tourmaline. It bears some resemblance to a granophyric "elvanite" from Goldsithney, Cornwall (BM. 50372)[1] (see p.15).

In thin section the feldspar appears to be microperthite and independent plagioclase is not seen. Biotite is replaced by tourmaline and opaque material, and tourmaline also occurs as incomplete spherulites and sheaves of radiating indigo-blue and brownish prisms and "needles". The number of this pebble is 7.609.BP.44/5. It is from Weeford Works, Canwell, $1\frac{1}{4}$ miles S. of Weeford, which supplied the paving cobbles for the road borders at Birmingham University.

Quartz-Porphyries

These are divided for convenience of description under the following headings: Quartz-feldspar-porphyries with biotite; quartz-porphyries with much tourmaline; and other quartz-porphyries.

Quartz-feldspar-porphyries. The quartz-feldspar-porphyries are remarkable for the large size of the quartz and feldspar insets, up to two or three millimetres across. Occasionally the feldspars are clear and glassy. These appear to be orthoclase but it is noted that glass-clear feldspar insets in a granite-porphyry boulder from the New Red Sandstone on Labrador beach, S. of Teignmouth, was found by Dr. Dunham to be sanidine (Scrivenor, 1948, p. 323).

Eight of these quartz-feldspar-porphyries with biotite have been sliced. The description of representative examples is as follows:— 2.172,173 and 174. Localities BP.44/3; 44/4 and 51/13 i.e., Weeford Works, Canwell and Sling Common, Clent.

The insets of quartz and feldspar are set in an aphanitic base, pallid brownish drab in colour on the cut face of the pebble but vinaceous buff on the surface. The feldspars are in two colours, pale pink and near white.

The thin sections show very abundant insets of quartz and of feldspar, in places crowded together. The quartz insets are embayed and corroded. The feldspar, as the two colours in the hand-specimen indicate, is of two kinds: orthoclase, often showing perthitic lamellae, and somewhat sericitized plagioclase showing albite twinning. There are some small biotites partly altered and opaque, but more frequently the biotite occurs with quartz and magnetite forming groups. These

[1]Numbers preceded by BM. refer to the collection in the Department of Mineralogy, British Museum (Natural History).

little clots of dark minerals are frequently in the angles between quartz and feldspar insets. Small amounts of tourmaline are associated with the biotite in them. The groundmass is a fine-grained aggregate of quartz and feldspar (Pl. 1, fig. 1). The pleochroism of the biotite is usually straw colour to nearly black, but sometimes straw colour to ivy green. The green colour is perhaps an indication of alteration.

One quartz-porphyry contains no biotite, but very small flakes of muscovite have developed in the groundmass and in pseudomorphs after plagioclase (?). This is from Keeper's Pool, Sutton Park (8.671.BP.35/1).

Quartz-Porphyries with much tourmaline. Pebbles in which tourmaline is well developed have special characters which should make them easy to match if ever their source of origin is found. A very good example is :— 7.614.BP.17/5, from Ridge Street, Wollaston Ridge.

This is a large, 18 cm., pebble. It shows irregular patches, 1 to 2 mm. across, of bluish black tourmaline, flakes of biotite (1 mm. long), and a few feldspar insets in a light brownish drab, aphanitic groundmass. The feldspars are mostly white, Carlsbad twins, up to 1 cm. long. Some of them have dark centres. There are also a few small pinkish feldspar insets.

The thin section shows large, Carlsbad-twinned orthoclase insets and smaller insets of quartz. Small patches of very fine-grained muscovite (sericite?) are probably pseudomorphs after plagioclase. Biotite flakes are frequent. They are partly altered but they still show pleochroism, dull yellow to very dark brown, or black. Tourmaline, pleochroic from nearly colourless to bright blue, is abundant. It occurs as small groups of crystals frequently arranged radially and penetrating the groundmass round about.[1] Occasionally some tourmaline in browner shades is seen replacing a mineral with rectangular outlines, probably biotite. The groundmass is microcrystalline quartz and feldspar. Muscovite occurs sparingly as very small flakes in the groundmass. Apatite is an occasional accessory. It may be noted that one of the large feldspar insets in the section encloses small flakes of biotite and occasional muscovite, small prisms of blue tourmaline, and small apatite prisms. Within the feldspar the biotite has been to some extent protected from alteration.

Altogether 17 sliced pebbles are listed as belonging to this group but some contain less tourmaline than the example described in detail and not all show the spherulitic grouping of the tourmaline prisms (7.541). In one case (7.608) tourmaline is partly replacing plagioclase and the colour of the fibres and prisms ranges from blue to nearly colourless. In another (8.717) tourmaline occurs partly replacing some of the feldspar as well as the biotite. The thin section of this pebble shows radiating prisms of tourmaline springing from the edge of one of the circular quartz-tourmaline areas. Rather similar features are seen in 7.622 from Repton.

Other quartz-porphyries. The other quartz-porphyries mostly have insets of feldspar as well as of quartz but the feldspars are not so large as in the pebbles described as quartz-feldspar-porphyries nor are they so numerous. Fifteen pebbles

[1]A good example of tourmaline in radiating groups is described below from a pebble from Budleigh Salterton (p. 12 and Pl. 1, fig. 5).

are described under this heading in the detailed catalogue. Their separation from the quartz-feldspar-porphyries on the one hand and the rhyolites on the other is somewhat arbitrary.

As an example one may take a large pebble from Warley Old Quarry (measuring $7 \times 6 \times 4$ cm.). This shows abundant insets of dark quartz crystals 1 to 2 mm. across and fewer of feldspar in an olive-buff to greyish olive groundmass (2.159, BP.52/6).

The thin section shows many insets of quartz and of feldspar in a somewhat turbid, speckled, microcrystalline groundmass. Feldspars are idiomorphic, slightly turbid, and they show perthitic lamellae. Opaque patches, rather rare, may represent biotite. The groundmass is a fine-grained and slightly turbid, quartz-feldspar aggregate. In places it is microspherulitic, but this structure is not very definite.

One pebble in this group is microspherulitic (7.547. BP.43/2). It is from Hopwas Sand Pit. In some respects it resembles a pebble from Watcombe in the Torquay district described by W. G. Shannon as "spherulitic quartz-orthophyre" (605=E21852).[1] (See p.14).

Another (2.175.BP.51/14) from Sling Common, with a microspherulitic groundmass has sericitized plagioclase and this, it may be noted, is similar to the sericitization shown by many of Shannon's pebbles from Maidencombe.

Two of the quartz-porphyries in this group are biotite-bearing. These may be important as they offer fairly good matches with a quartz-biotite-porphyry from Withnoe Down in the Maker peninsula, East Cornwall, which is described below (p. 15). The following is a description of one of these biotite-bearing types : 7.551.BP.51/19, from Sling Common, Clent.

This has insets of quartz and two kinds of feldspar. The latter are partly small pink crystals less than 1 mm. in length, and partly white insets up to 2×4 mm. in dimensions. The white insets are the more numerous. The aphanitic base is near orange vinaceous on a fresh fracture, but dark vinaceous on the worn surface.

In thin section it is seen that biotite is present but almost everywhere is altered and replaced by opaque material. The two kinds of feldspar are clearly distinguishable. Original plagioclase, white in the hand-specimen, is represented by micaceous pseudomorphs ; the pink insets are slightly turbid Carlsbad twins of orthoclase. Occasional flakes of muscovite are present : these are probably secondary. The groundmass is a microcrystalline quartz-feldspar aggregate.

Compared with this the Withnoe Down rock has more frequent insets and neither the feldspar nor the biotite show much alteration : nor are later quartz veins seen cutting the rock.

Another of the biotite-bearing quartz-porphyries (7.604.BP.50/1) from Longton, N. Staffordshire, is remarkable for the unaltered condition of the biotite which is pleochroic from straw yellow to very dark brown. The section of this pebble shows

[1]The three figure numbers refer to a collection of pebbles from the Permian breccias of the Torquay district described by W. G. Shannon and presented by him to the Geological Survey Museum. Five-figure numbers preceded by "E" refer to the Geological Survey register of rock-specimens. Shannon's collection is further referred to below (p. 14).

some altered (? serpentinized) crystals with the shape of olivine. There are some small areas of tourmaline in the microcrystalline groundmass.

Tourmaline with pleochroism, E colourless and deep bluish grey-green, O dark olive-buff to dull greenish black, was noted in another pebble comparable with the biotite-bearing type described above. This has large feldspar insets, up to 6 mm. (9.802.BP.51L/84).

Another tourmaline-bearing example, a pebble from the Drift, showing dark specks and rods in a very fine-grained (felsitic) groundmass (7.685.BP.61/16) is rather like Shannon's tourmaline-quartz-porphyry from Maidencombe (554= E21907) but this has no fresh biotite and carries abundant quartz insets.

Rhyolites

Under this heading are described pebbles similar in mineral composition to the quartz-porphyries but showing flow structure. A good example is a boulder from the Drift at New End, Ridgeway, but almost certainly derived from the Bunter Pebble Beds. (2.99.BP.61/15).

It is a typical rhyolite with flow structure clearly visible and with frequent insets of quartz, 1 to 3 mm. across, and some very pale cream coloured feldspar, 1 to 2 mm. in diameter, in a buffy brown aphanitic base.

In thin section the quartz insets are seen to be much embayed and the feldspars slightly turbid orthoclase. The groundmass, yellowish brown in colour in thin section, with well developed contorted flow structure, was no doubt originally glass. It now consists of an extremely fine-grained quartz-feldspar aggregate. Some elongated areas have a more coarse-grained, granular structure. Thin quartz veins traverse the section, running across the banding (Pl. 1, fig. 2).

Similar but with the devitrified base much paler in thin section is a large olive-brown pebble from New Wood, Wollaston (7.586.BP.17/3). Pink feldspars up to 4 mm. long are conspicuous in the pebble, and the thin section shows also some sericitized feldspar that probably represents plagioclase.

There are many variations to be found among the pebbles of rhyolite.

A pale, quaker-drab pebble (8.716.BP.40/12) shows perlitic cracks which are clearly visible on the surface of the pebble (Pl. 1, fig. 3).

Several of the rhyolites show spherulitic structures. Elegant spherulites with only small amounts of interstitial "groundmass" form bands in one pebble (9.726.BP.43/5), from Hopwas Sand Pit, and well-developed spherulitic structure is seen in a fine-grained quartz-feldspar groundmass in another (2.98.BP.61) from the Drift.

Some of the rhyolites contain tourmaline and some carry biotite. These, like the quartz-porphyries with much tourmaline, should be easily matched. A good example of this group is a pebble, bluish black in colour, speckled and streaked with cream, and showing pronounced flow-structure and occasional black and grey xenoliths, 1 to 2 cm. long. In this there are rather infrequent small insets of quartz and a few of altered feldspar, and abundant small rectangular sections of biotite, much of it fresh enough to show its pleochroism ; straw-yellow to dark orange-brown. The groundmass is microcrystalline to cryptocrystalline, banded and

showing flow-structure. Pale blue tourmaline is abundant. This tends to concentrate in bands and there are some long thick bodies, perhaps xenoliths, in which small prisms of greenish tourmaline occur as well. The blue prisms form small tufts along the edges of some of these dark patches.

Another example is a pebble from Oakamoor, nr. Cheadle, with a pale grey to light vinaceous fawn " felsitic " base, lined and banded by dark bluish black lines. (7.601.BP.41B/4). In this the flow-banding is very well developed, bands being emphasized by the distribution of the fine-grained tourmaline. Biotite in this case is completely altered, being replaced partly by tourmaline.

If the Withnoe Down rhyolite (see below p. 15) were tourmalinized and the feldspars were altered it might resemble such a rock as this.

Small xenoliths occur in some of the rhyolites already described and in some of the pebbles xenoliths of other igneous rocks or of sedimentary rocks are frequent. Some of these pebbles may be derived from rhyolitic ashes. One described with these rhyolites, containing frequent xenoliths, is perhaps a lapilli-tuff (2.126.BP.51/8), from Sling Common. It consists of rounded pieces of quartz-porphyry, or rhyolite, with insets of quartz and feldspar and opaque pseudomorphs after biotite in a crypto- to microcrystalline groundmass. Between the " lapilli " is brecciated material consisting of quartz, feldspar, and broken groundmass with scattered opaque material. This bears some resemblance to Shannon's rhyolite pebbles from Watcombe (603, 606, 608, 610) but there are no quite close matches.

An example of rhyolite with apparently all igneous xenoliths is 8.640.BP.44/7, from Weeford Works, Canwell. This pebble, slate olive or dark purple drab in general colour, has some fragments paler purple and smaller ones buff or cream. It appears to be a rhyolitic ash with flow-banding preserved in the very fine-grained microcrystalline groundmass which is crowded with fragments of feldspar and various rock fragments. None of the xenoliths are definitely identified as sedimentary. They all seem to be derived from other rhyolitic or microgranitic " felsitic " rocks.

Xenoliths of sedimentary rocks are abundant in a pale grey to pale olive-buff pebble (2.95.BP.51/35), from Sling Common. Some of the xenoliths are grey but one measuring $1 \times 0{\cdot}5$ cm. is dull red. Angular fragments of quartz and feldspar are also abundant. These resemble the insets in the rhyolitic pebbles. There are also some bleached altered biotites and occasional stout prisms of tourmaline to be seen in the thin section. Among the xenoliths are shales or schists, and fine-grained greywackes. The last have angular quartz grains in a fine-grained base containing fibres of colourless mica (Pl. 1, fig. 4). It was noticed in the thin section of this pebble that the groundmass is crowded with minute needles or fibres perhaps of mica or chlorite (or both). The smallest fibres are colourless and have positive elongation, thus agreeing with mica, but rather larger flakes are dull green and have negative elongation, agreeing with chlorite.

There is another instance of the occurrence of chlorite in one of the biotite-rhyolites in a pebble from Hopwas Sand Pit (8.710.BP.43/4). There it replaces feldspar insets.

Perhaps one of the pebbles from Sling Common catalogued with Breccias

(7.624.BP.51/25) should rather be described as a tuff. In the pebble one sees dark red angular fragments lying in a paler matrix. Within the fragments themselves there are parts of still darker colour. These fragments consist of chips of fine-grained quartzose rocks, or microcrystalline " felsitic " rocks, in a dark ferruginous base with an outer zone of paler colour. In this fine-grained base are " swirls " and " flow " lines. Outward from the brown fragments lie still paler bands. The main matrix, carrying bleached particles of the larger fragments, is colourless in thin section. It appears to consist wholly of quartz, and there seems to be a tendency for somewhat elongated grains to take on a roughly rectangular arrangement. This section is figured Pl. 1, fig. 6.

THE SEARCH FOR THE SOURCE OF THE BUNTER PEBBLES

Many petrographers have examined small collections of Bunter Pebbles from the Midlands and have made brief reports on them. References to these will be found in the bibliography (p. 16). More considerable papers on the subject were written by T. G. Bonney (1880, 1883), T. H. Waller (1889) and O. H. Shrubsole (1903). With the notable exception of T. G. Bonney all these petrographers have suggested a southern or south-western source for the pebbles of igneous rocks they have examined.

Palaeontologists also have suggested southern sources for the quartzites containing Ordovician and Devonian fossils and have named Normandy as the most probable source for the former. Some pebbles, from North Staffordshire, containing Upper Llandovery fossils, unknown in Midland outcrops, are considered by A. Lamont (1940, 1946) to have had a sub-local source.

L. J. Wills, having considered the evidence afforded by the extensive collection of the Bunter Pebbles made at Birmingham and by the publications referred to above, gave in his book on Concealed Coalfields (1956, pp. 112–113), his conclusions as follows :

" . . . the predominance of quartzite and vein-quartz pebbles (together averaging 80–90 per cent. by weight) ; the variety of rock types, sedimentary, metamorphic and volcanic ; the southern facies of the fossiliferous quartzites, some Ordovician, some Devonian; and the numerous tourmaline-bearing rocks, all point to a southerly derivation from a land-surface made up of outcrops of rocks of pre-Coal Measure age, unknown or rare in the Midlands . . . " and he thinks that these outcrops may now be buried under Mesozoic rocks in southern England.

Wills also considers that sources nearer at hand than southern England must be sought for some of the exceptionally large boulders of quartzite (some undoubtedly Cambrian), and for quartzites containing Llandovery fossils (as Lamont had suggested), and perhaps also for some of the Carboniferous crinoidal cherts and of the deeply leached igneous rocks that are found along with the harder pebbles. He has also given consideration to the possible derivation of the Bunter Pebbles from earlier conglomerates, a suggestion made by several earlier authors (Wills, op. cit. footnote p. 113).

The large number and variety of pebbles of igneous rocks available in the Birming-

ham collection seemed to offer a new opportunity to look for more definite evidence as to some of the source rocks of the pebbles either at outcrop or in earlier conglomerates. It was with this end in view that a petrographic study of the sliced pebbles in the collection was undertaken to be followed by comparisons with rocks from areas thought likely to provide similar types of igneous rocks.

Thin slices of the Bunter Pebbles described in the preceding section of this paper have been compared side by side firstly with pebbles from the Bunter Pebble Beds of the Budleigh Salterton district in order to ascertain whether the same kinds of igneous rocks are represented among the pebbles of the two areas. A similar comparison was then made with rocks *in situ* and with pebbles in conglomerates from Normandy, and from Pembrokeshire ; with pebbles in the Permian breccias of the Torquay district ; and with rocks *in situ* in Cornwall and Devon.

The results of all these comparative studies are set out below.

Bunter Pebbles from the Budleigh Salterton district.

Pebbles from the cliff at Budleigh Salterton, Devonshire, and from several quarries in the vicinity were collected by Professor L. J. Wills for comparison with Midlands Bunter pebbles. Some two dozen of the pebbles of igneous types of rock were sliced and these have been examined and compared side by side with any of the Midland pebbles in the Birmingham collection that they seemed to resemble. All these were either fine-grained quartz-porphyries or rhyolites.

A few very close matches were obtained.

Examples among the quartz-porphyries are :

2.165. A quartz-feldspar-porphyry with biotite from the west end of the main cliff at Budleigh Salterton is comparable with one from the drift at Wildmoor near Bromsgrove (7.541.BP.61/12).

2.179. A quartz-porphyry with much tourmaline, also from the cliff, compares closely with the Midlands pebble from Ridge Street, Wollaston, described above (7.614.BP.17/5, p. 7). In this case the comparison is so close that one can hardly doubt that the pebble from Budleigh and the matching pebble from the Midlands came from the same source.

The Budleigh specimen is so striking in its characters that a full description is appended and a photomicrograph of the section is reproduced in plate 1, fig. 5.

It is a large cobble with a compact, aphanitic groundmass, pale olive-grey in colour. In this groundmass are many dense black patches rectangular in shape and up to 1 cm. across, also others less angular in outline, and some, nearly circular, with radial structure. These are all tourmaline. Along with them are a few glassy quartz crystals up to 3 mm. across, and pink-stained feldspars occasionally as much as 2 cm. in length. The thin section shows many insets of clear quartz and one of feldspar insets. This is orthoclase. There are also a few small insets of twinned plagioclase. Biotite flakes have been completely replaced by tourmaline, and some of these pseudomorphs are enclosed by the feldspar insets. Very striking in the thin section are circular areas composed of fine-grained tourmaline, both blue and brown, and clear microcrystalline quartz. Sometimes a stout tourmaline crystal acts as a central nucleus. The effect is as if tourmaline had replaced feldspar over a spherical area in the groundmass leaving only the quartz-tourmaline aggregate occupying the space. (Pl. 1, fig. 5.) The colours of the tourmaline range from yellowish brown to bluish green, and from nearly colourless

to dark blue. The groundmass of this rock is a very fine-grained aggregate of quartz and feldspar similar to that in some quartz-feldspar-porphyries.

There are several more quartz-porphyries with tourmaline in the collection from the Budleigh Salterton district. One of them (8.718) from a gravel pit (BS1) 3 miles NW. of Budleigh, is a fairly good match for a Midlands pebble (7.614 from Ridge Street, Wollaston Ridge) though this carries more tourmaline and has no muscovite in the groundmass, as 8.718 has.

Rhyolite pebbles are numerous in the collection from Devonshire. The common kind contains frequent rather small quartz insets, often rounded and embayed, and insets of slightly turbid orthoclase in a cryptocrystalline groundmass. Short curved lines in the groundmass may represent traces of glass shards. Flow structure is fairly well developed. A few thin quartz veins traverse the pebbles. No difficulty was found in matching rhyolite pebbles of this kind with pebbles from the Midlands. Five good examples were found from four localities.

Other rhyolites among the Budleigh Salterton pebbles have a groundmass with fine-grained granular texture. Some of these (e.g. 2.166) show occasional indications of spherulitic structure. Something of the same kind was noted among the rhyolites of the Midland pebbles.

Some of the Budleigh Salterton rhyolite pebbles carry small xenoliths of sedimentary rocks. An example of these (8.719) is a pale olive-buff pebble with abundant quartz insets (up to 2 mm. across) and various xenoliths in a devitrified glassy base with well-developed flow structure. Some of the xenoliths are of sedimentary rocks but others appear to be of biotite-granite with some (secondary) muscovite. Some Midlands pebbles resemble this Budleigh type but they do not show the coarse-grained "granitic" inclusions (see p. 10).

One would like to have had available a larger and more representative collection from the district on which to base a comparison of the igneous rocks represented by pebbles from Budleigh Salterton and the Midlands. However, the collection from Budleigh made by Professor Wills has been sufficient to show that there are in the Budleigh Salterton district pebbles of igneous rocks of the same kinds as those occurring as pebbles in the Bunter of the Midlands. Except perhaps in one case, it cannot be claimed that pebbles from the two areas are of identical rocks. On the other hand there are sufficient near matches to allow one to conclude that pebbles from both areas could have been derived, directly or indirectly, from outcrops of rhyolites and quartz-porphyries of the same petrographical province, and probably from the same region.

"*Microgranites*" *from Normandy*

Owing to the kindness of Mme. E. Jérémine I was able to examine thin sections of the "*microgranites*", probably of Precambrian age, described by her from La Hague, a narrow peninsula running north-west from Cherbourg.

Some of these "*microgranites*" contain small insets of quartz and feldspar like the quartz-porphyries and some others have textures approaching those of rhyolites. Rhyolite pebbles occur also in a conglomerate at the base of the Cambrian. They are regarded by A. Bigot and Mme. Jérémine as similar to the rhyolites of Jersey.

Sections of these rhyolites and "*microgranites*" from Normandy were compared with Bunter Pebbles but no matching specimens were found.

"Quartz-felsites" from Pembrokeshire

"Quartz-felsites" from St. David's described by Thomas Davies for Henry Hicks (1878) and other specimens from the Precambrian of this district were compared with Bunter Pebbles. Although there is at St. David's an association of quartz-porphyries and related rocks with flow structure, and so resembling rhyolites, they do not appear to match any of the quartz-porphyries and rhyolites of the Bunter Pebbles. The St. David's "quartz-felsites" tend to develop micrographic and spherulitic structures rather than the microcrystalline equigranular texture of so many of the Bunter Pebbles. Some of the St. David's "quartz-felsites" have irregular areas of green chlorite, but any relics that might represent original biotite are very rare.

Pebbles from the Permian breccias of the Torquay district, Devon

There are two collections of these pebbles in the Geological Survey Museum ; one made by W. G. Shannon (1927 and 1933) and a smaller one made by J. B. Scrivenor (1948). Examination of these enables one to report that there is a certain degree of "family" likeness between some of the pebbles of the Torquay Permian and certain pebbles from the Midland Bunter. In no one instance can one say that the Bunter pebble from the Midlands and its parallel from the Torquay district Permian are from the same rock mass or even from separate outcrops of the same kind of rocks, but one gets the impression that the two sets of pebbles may have been derived from rocks of the same age and formation. It must be noted that some of Shannon's "orthophyre" pebbles from Maidencombe in the Torquay district show sericitization affecting the groundmass minerals to a marked degree. This is not found to be nearly so advanced in the Midlands pebbles although feldspar insets are often replaced wholly or in part by colourless mica.

Rocks in situ in Cornwall

Tourmalinized breccias and other "schorlaceous" rocks. Wills reports that these rocks are extremely common in outcrop exposures of the Pebble Beds.

I have examined some of these but I have not compared them side by side with Cornish rocks. They have, however, been so compared by several other petrographers beginning with T. H. Waller of Birmingham (1889). C. A. Matley (1914) noted in his collection of Bunter pebbles from the Drift in the Midlands many schorl-bearing rocks and he compared them with tourmalinized rocks from Cornwall and Devon. H. H. Thomas described two selected specimens from Matley's collection, a "schorlaceous breccia" and a "schorlaceous granite". He gave the opinion that "it is hard to assign any other source to these pebbles than the West of England for in that region alone can the types be matched with any degree of closeness" (in Matley, 1914, p. 214).

Elvans from central and south-west Cornwall. All the specimens of Cornish elvans from central and south-west Cornwall in the Department of Mineralogy, British Museum (Natural History) were examined but only five were found to hold out

any hope of being a near-match for any of the Midland Bunter pebbles. These are :

B.M.53069. Quartz-biotite-porphyry, Relistian mine, Gwinear.
B.M.50371. Quartz-biotite-porphyry, Marazion quarry.
B.M.50372. Biotite-granophyre, Goldsithney (mine), Sithney, Breage.
B.M.53078. Quartz-feldspar-porphyry with tourmaline, Chimney Rock, Penzance.
Phillips Collection No. 335. Quartz-biotite-porphyry with tourmaline, Seal Hole cliff, St. Agnes.

I think the most that can be claimed with regard to these Cornish elvans is that the comparisons show that an area with the same sort of quartz-porphyries as those associated with the Cornish granites could provide material similar to that of the quartz-porphyries of the Bunter Pebble Beds at Budleigh Salterton and in the Midlands.

" Felsites " (quartz-porphyries and rhyolites) from the Maker Peninsula, Cornwall. These rocks are exposed in old quarries on Withnoe Down and on the shore at Cawsand Bay. They have been described by J. S. Flett and W. A. E. Ussher (1907, p. 111–115), and by W. G. Tidmarsh (1932). The last author regarded these rocks as early Permian and probably older than the Exeter lavas.

Many specimens of these quartz-porphyries and rhyolites from the collections at the Geological Survey, at Birmingham University, and in the Department of Mineralogy, British Museum (Natural History) were compared with the Bunter pebbles. No Bunter pebbles exactly matching the Withnoe rhyolites were found but, on the other hand, the Withnoe quartz-porphyries call to mind several quartz-porphyries from the Bunter and two quite reasonably good matches were found (7.546 and 7.551 from Sling Common, Clent).

An important difference between the Withnoe porphyries and the Midlands pebbles which most nearly resemble them is that there is no tourmaline in the Withnoe rocks. Nevertheless one gets the impression that if rocks like those of Withnoe and Cawsand Bay occurred in some other area where tourmalinization had affected them there would be a good chance of matching some of the Bunter pebbles with them. Unfortunately no other outcrops of related rhyolites and quartz-porphyries of the same age are known in England.

CONCLUSIONS

The conclusions that can be drawn from all the above comparisons are hardly any more definite than those arrived at by other petrographers who from brief examination of small collections of Bunter pebbles suggested a southern or south-western source for the pebbles.

It can be stated, however, that some pebbles in the Budleigh Salterton Pebble Beds are similar to pebbles in the Bunter Pebble Beds of the Midlands pointing to the derivation of pebbles in these two areas from outcrops of closely related rocks though not necessarily from outcrops in one and the same region.

The comparisons of Bunter Pebbles with rocks *in situ* or in conglomerates has shown that so far none of the rocks that supplied the igneous types among the

Bunter Pebbles have been found at visible outcrops in England and Wales, nor, so far as the rather limited enquiry has gone, in Normandy.

It can be inferred, therefore, that the outcrops which supplied the pebbles are now concealed. It can perhaps also be inferred that the sources of rocks for the igneous pebbles are unlikely to be found among rocks like the Precambrian " quartz-felsites " of St. David's, or the " *microgranites* " of La Hague but that they are much more likely to be found among rocks related to, but not identical with, one or all of the three groups of rocks from Cornwall and Devon examined.

These are, in order of closest comparisons :—

(a) quartz-porphyries and rhyolites of the Maker Peninsula ;

(b) quartz-porphyries of the " elvans " associated with the granites of Cornwall and Devon.

(c) rocks of the same age and formation as those that supplied the igneous pebbles to the Permian breccias of the Torquay district.

In conclusion I wish to acknowledge my indebtedness to Professor L. J. Wills for constant help during the many years since this work was first undertaken, and to Dr. G. F. Claringbull, Keeper of Minerals, for facilities to carry on the work in his department of the British Museum (Natural History).

REFERENCES

Bigot, A. and Jérémine, E. 1923. Observations nouvelles sur la géologie de la Hague (Manche). *C.R. Acad. Sci. Paris*, **176** : 221–222.

Bonney, T. G. 1880. Note on the pebbles in the Bunter Beds of Staffordshire. *Geol. Mag.* n.s., dec. 2, **7** : 404–407.

—— 1883. Second note on the pebbles in the Bunter Beds of Staffordshire. *Geol. Mag.* n.s., dec. 2, **10** : 199–205.

Davies, T. 1878. Appendix [to paper by Henry Hicks] on the microscopic structure of some Dimetian and Pebidian rocks from Pembrokeshire. *Quart. Journ. Geol. Soc.* **34** : 164–166.

Flett, J. S. *in* Ussher, W. A. E. 1907. Explanation of Sheet 348. *Mem. Geol. Surv. E.* and *W.*: 114–115.

Jérémine, E. 1930. Étude pétrographique de la Hague. *Bull. Soc. Géol. Fr.*, ser. 4, **30** : 3–50.

Lamont, A. 1940. Derived Upper Llandovery fossils in Bunter Pebbles from Cheadle, North Staffordshire. *Cement, Lime,* and *Gravel*, **15** : 26–30.

—— 1946. Fossils from Middle Bunter Pebbles collected in Birmingham. *Geol. Mag.* **83** : 39–44.

Matley, C. A. 1914. Note on the source of the pebbles of the Bunter Pebble-beds of the English Midlands. *Geol. Mag.* n.s., dec. 6, **6** : 211–215.

Phemister, J. 1936. *Summary* of *Progress Geol. Surv. Gt. Br.*, Part 1, p. 83.

—— 1946. *In* Richardson, L. and others. The geology of the country around Witney. *Mem. Geol. Survey E.* and *W.*, p. 109.

Sabine, P. A. 1949. The source of some erratics from North-Eastern Northamptonshire and adjacent parts of Huntingdonshire. *Geol. Mag.*, **86** : 257.

Scrivenor, J. B. 1948. The New Red Sandstone of South Devonshire. *Geol. Mag.* **85** : 323.

Shannon, W. G. 1927. The petrography and correlation of the Permian Rocks of the Torquay Promontory. *Proc. Geol. Assoc. London*, **38** : 135–139.

—— 1933. *In* Explanation of Sheet 350, *Mem. Geol. Surv. E.* and *W.*, 2nd edit.: 103–104.

SHRUBSOLE, O. H. 1903. On the probable source of some of the pebbles of the Triassic Pebble-beds of South Devon and of the Midland Counties. *Quart. Journ. Geol. Soc.* **59** : 311–331.

THOMAS, H. H. 1914. *In* MATLEY, C. A. 1914. *Geol. Mag.* n.s. dec. 6, **6** : 211–215.

TIDMARSH, E. G. 1932. The Permian lavas of Devon. *Quart. Journ. Geol. Soc.* **88** : 712–733.

USSHER, W. A. E. 1907. The geology of the country around Plymouth and Liskeard. With notes on the petrology of the igneous rocks by J. S. Flett. *Mem. Geol. Surv. E.* and *W.* Explanation of Sheet 348 : 111–112.

WALLER, T. H. 1889. The petrology of our local pebbles. *Midland Naturalist,* **12** : 1–16.

WILLS, L. J. 1956. Concealed Coalfields. A palaeogeographical study of the stratigraphy and tectonics of mid-England in relation to coal reserves : 112–113.

PLATE 1

(*Photomicrographs by Mr. D. L. Williams, Dept. of Mineralogy*)

FIG. 1. Quartz-porphyry with biotite (black), and insets of quartz (white) and feldspars (grey). From Weeford works, Canwell. [2.173.BP.44/4] (see p. 7).

FIG. 2. Rhyolite showing flow structure and frequent insets of quartz (white) and feldspars (dark). A boulder from New End, Ridgeway. [2.99.BP.61/15] (see p. 9).

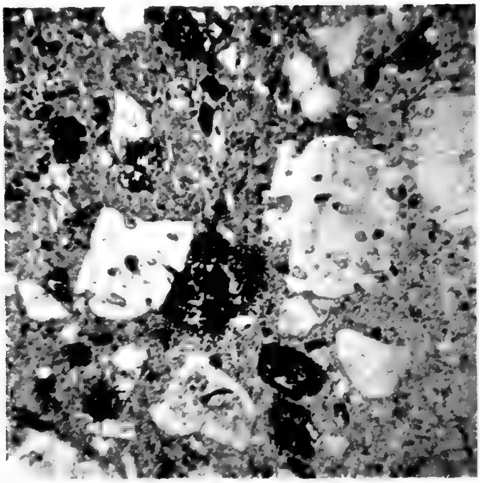
FIG. 3. Rhyolite showing perlitic cracks. Insets are replaced by quartz mosaic and vesicles are quartz-filled. From Hilton, near Cheadle, Staffs. [8.716.BP.40/12] (see p. 9).

FIG. 4. Rhyolite showing insets of quartz and feldspar, xenoliths of sedimentary rock, some bleached biotites, and tourmaline. From Sling Common, Clent. [2.95.BP.51/35] (see p. 10).

FIG. 5. Pebble of tourmalinized quartz-porphyry from the west end of the main cliff at Budleigh Salterton. The section shows tourmaline in radiating groups, also tourmaline replacing biotite (black) and many insets of quartz (white). [2.179/S7 from BS6] (see p. 12).

FIG. 6. Pebble of tuff (?) with dark red angular fragments in a paler matrix. From Sling Common, Clent. [7.624.BP.51/125] (see p. 11).

All magnifications are $\times 8$. Photos taken in polarized light but not with crossed polaroids.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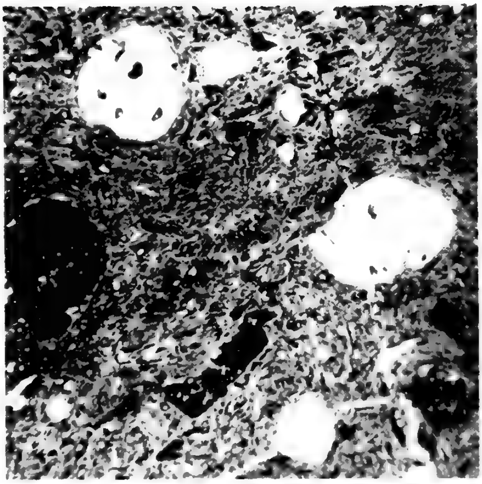
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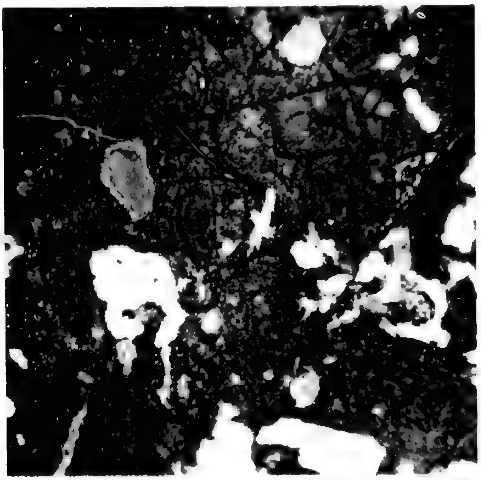
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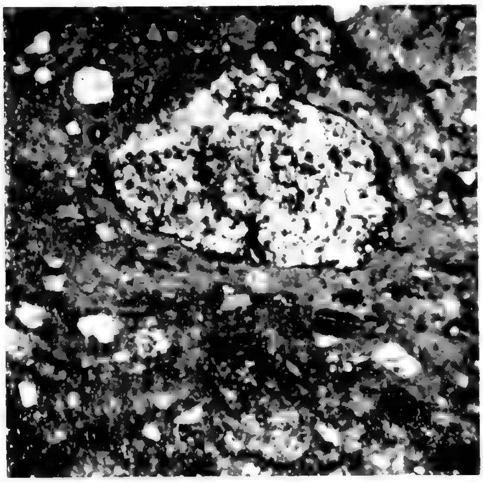
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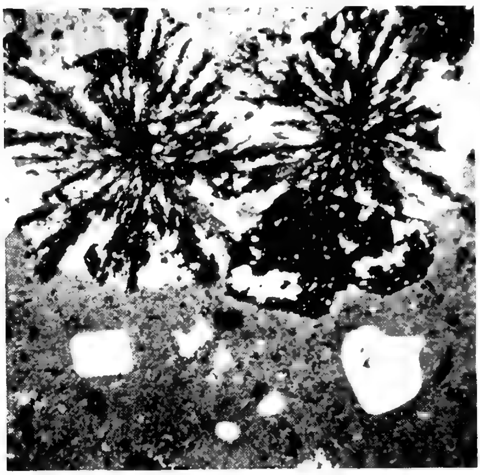
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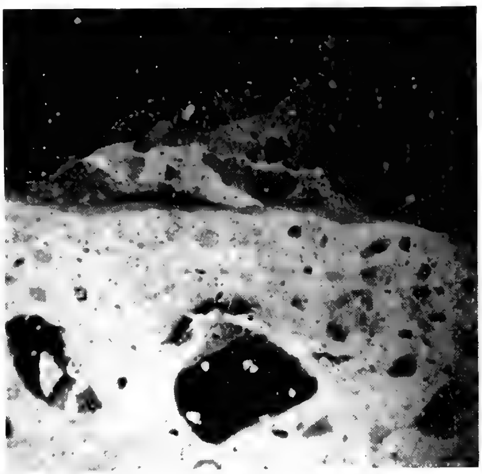
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